Effects of Cryogenic Treated Wire Electrode on the Surface of an EN-31 Steel Machined by WEDM

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Abstract—*The main goal of wire electrical discharge machine users and manufactures is to achieve high precision machining i.e. with desired accuracy and minimum surface damage. Brass wire electrode is used as a tool in wire electrical discharge machining (WEDM). Due to diversification of industrial applications and fields, demand is expanding for the wire electrodes to have performance superior to that of plain brass wire. This paper presents the results of the effect of Cryogenic treated brass wire electrode on the surface of an EN-31 steel machined by WEDM. Full factorial experimental design strategy is used in the experimentation. Three process parameters, namely type of wire electrode (untreated and cryogenic treated brass wire electrodes), Pulse width, and wire tension have been considered. The process performance is measured in terms of surface roughness (SR). ANOVA results indicated that all the process parameters have significant effect on SR. Scanning electron microscopy highlighted the important features of WEDMed surfaces with cryogenic treated and untreated brass wire electrode. Surface roughness is improved with cryogenic treated brass wire electrode.*

Keywords: *WEDM, Brass wire, Cryogenic treated wire, Surface roughness*

Introduction

Recent development in technology has led to the vast use of engineering materials with high strength and hardness. Traditional machining processes have been replaced by nontraditional manufacturing processes such as wire electrical discharge machining (WEDM). High strength and low ductility materials can easily be machined with high accuracy with WEDM [1]. In WEDM, material is removed by series of discreet discharges between wire electrode and work piece in the presence of dielectric. For those materials, which require high strength and good wear resistance (Die materials and press tools etc.), WEDM has been widely adopted. Surface generated by WEDM includes many defects such as craters due to electrical sparks, alloying of tool electrode material on work piece surface. The surface characteristics of work piece machined by WEDM plays a vital role in determining the quality of the material. There is a migration of work piece element to tool at low and high current intensities. The quality of surfaces generated by various machining methods and machining parameters can be studied by scanning electron microscope (SEM) photographs. Rajurkar et al [2] concluded that the higher peak current resulted in a rougher workpiece surface. Energy dispersive spectrometry revealed that some amount of the wire electrode material from WEDM gets deposited onto the workpiece surface. SEM micrographs of different surfaces machined by WEDM with long pulse duration and short pulse duration indicate a different surface morphology. It was observed that discharge craters on the surface capitulate with short pulses were small and deep, where as the discharge craters on the surface capitulated with long pulses was large and shallow. The two surfaces had different diffuse reflection [3]. Studies have indicated that surface roughness of EDMed surface depends upon the pulse on time and peak current [4-6]. Surface roughness of workpieces machined by WEDM is determined by pulse on time and peak current regardless of the type of material being machined [7]. New pulse generators were developed by tool builders to achieve high quality surface and accurate machining [8-9]. Chen et al. [10] proposed that there is a migration of workpiece elements to the tool surface when high and low current intensities are used. Thomosan [11] studied the surface modification of tool and indicated that both electrodes, tool and work piece, suffer a surface modification during the electrical discharge machining process. Few attempts have been made to investigate the effect of high performance wire electrodes on performance characteristics in WEDM. High performance electrical discharge machining wire is expected to provide high cutting speed, better accuracy and improved surface finish. Aoyama et al [12] and Kuroda et al. [13] developed high performance coated wire having high conductivity for better flusibility. High performance Coated brass wire electrodes improves the cutting speed and surface finish significantly [14-15]. But these high performance wires are not only costlier but also cause many impurities in dielectric fluid and other problems such as environmental hazards [16]. For many years, sub zero treatment of metals has been used as a means of improving the surface hardness and thermal stability of the metals [17]. Shallow Cryogenic treatment refers to the treatment of materials at very low temperature, generally around-1100C. Deep Cryogenic treatment refers the treatment at around -1840C. Cryogenic treatment affects the entire cross-section of the metals. Aluminum, brass, copper, tin and lead used in electronics industries exhibit better wear resistance, service life and conductivity after cryogenic treatment [18]. The useful life of an electrical contact may be extended significantly by exposing the contact to a predetermined relatively low temperature [19]. It is reported by Zhisheng et al. [20] that cryogenic treatment of electrodes used in spot welding significantly improves performance of the process. The literature survey indicates that most of the research has been directed towards surface characterization of WEDMed workpieces with plain brass or coated wire electrodes. Few attempts (Aoyama et al. [12], kuroda et al. [13] and Okada et al. [22] have been made to study the performance of WEDM with high performance wire electrodes as these electrodes have high thermal and electrical conductivities as compared to plain brass wire electrodes. Machining speed of Wire-EDM is related with conductivity of wire electrodes and cryogenic treatment enhances this property. The aim of this study is to investigate the effects of cryogenic treated brass wire electrode on surface roughness of workpiece.

Experimental

Materials and Methods

Work piece used in this study was EN31 steel plate of thickness 11mm. The properties of workpiece are mentioned in Table1. A Robofil 290 CNC wire cut EDM machine was used in this study. Three spools of wire electrode were taken for experimentation. The properties of brass wire electrodes are mentioned in the Table 2.

Table 1: Properties of work Piece Material

Material	Chemical Composition	Hardness (HRC)	Thickness
En-31	C-1.0% Si-0.31 % Mn-0.50 % P- 0.31 % S-0.042 % Cr-1.40%	58	11 mm

Experimental Design

The primary aim of this experimentation was to study the effect of cryogenic treated wire electrode on surface roughness of WEDMed work-pieces. Full factorial experimental design strategy was used in this experimentation. Three control variables, namely Type of wire, Pulse width and Wire tension are used in this experimentation, keeping remaining machining parameters constant. These machining conditions were chosen based on preliminary experimentation. Three levels for each control variables were selected for the full factorial experiment. Each machining condition has three replicates. Replications compute the variability of measurements within each unique combination of factors and also it allows estimating pure error in the experiments. An estimate of the pure error can be used to evaluate the size and statistical significance of the variability. The range and level of process parameters are shown in Table 3. The range of these parameters is selected on the basis of preliminary experiments. The values of fixed parameters are also shown in Table 3.

Table 2: Properties of Brass Wire Electrode

Material	Chemical composition	Hardness (VHN)	Tensile Strength	Conductivity (% IACS)
Untreated Brass wire	Cu 63% Zn37%	255	905N/ mm2	21%
Shallow cryogenic treatment (-110oC)	Cu 63% Zn37%	220	850 N/ mm2	27.6%
Deep cryogenic treatment (-180oC)	Cu 63% Zn37%	217	841N/ mm2	29.3%

Results and Discussion

27 experiments were conducted at different settings of control variables as specified in table 4. After machining the work piece at different run orders the work pieces were washed and cleaned. Surface roughness values were measured with Surf Tester (SJ201). Mean values of surface roughness are given in table 4.

Table 3: Control Parameters and Their Levels

Designation	Control Parameters	Levels		
		L 1	L2	L3
A	Type of wire	Untreated brass wire	Cryogenic treatment (-1100C) brass wire	Cryogenic treatment (-1100C) brass wire
B	Pulse width(μs)	0.4	0.8	1.2
C	Wire tension (daN)	0.6	1.3	2.0
Fixed Parameters				
Time between two pulses		10 μs		
Size of wire		0.25mm		
Thickness of workpiece		11 mm		
Angle of cut		Straight		
Cutting voltage(V)		-80		
Short pulse time		0.2 μs		
Injection pressure		4bar		
Wire feed rate		8m/min		
Servo reference voltage		35 V		

Table 5: ANOVA for Surface Roughness

Source	Sum of Squares	df	Mean Square	F Valu	p-value Prob > F
Model	7.70	18	0.43	53.34	<0.0001 significant
A-A	0.27	2	0.13	16.58	0.0014
B-B	6.44	2	3.22	401.59	0.0001
C-C	0.36	2	0.18	22.34	0.0005
AB	0.059	4	0.015	1.83	0.2162
AC	0.12	4	0.031	3.88	0.0488
BC	0.45	4	0.11	14.04	0.0011
Residual	0.064	8	8.022E-003		
Cor Total		7.77	26		
Std. Dev.		0.090		R-Squared	0.9917
Mean		2.17		AdjR-Squared	0.9731
C.V.%		4.14		Pred R-Squared	0.9059
PRESS		0.73		Adeq Precision	22.522

Table 4: Full Factorial Experimental Design

Order Runs	Factor A	Factor B	Factor C	Mean Surface Roughness (SR) µm
1	2	1	1	1.55
2	1	2	1	2.35
3	3	2	3	2.05
4	2	2	2	2.15
5	3	1	2	1.25
6	3	3	2	2.92
7	3	2	2	2.35
8	2	2	3	2.25
9	1	3	3	2.85
10	1	1	3	1.85
11	1	3	1	2.67
12	1	1	1	1.75
13	1	2	2	2.45
14	2	2	1	1.95
15	1	1	2	1.48
16	3	3	1	2.34
17	3	3	3	2.86
18	2	3	1	2.25
19	2	3	2	2.90
20	3	2	1	1.80
21	2	1	3	1.75
22	1	2	3	2.40
23	3	1	3	1.55
24	3	1	1	1.45
25	1	3	2	2.90
26	2	1	2	1.35
27	2	3	3	3.05

The analysis of varaiance has been performed in order to discern the contribution of signifiacnt parameters towards response (SR). The ANNOVA for SR data is shown in Table 5.

The ANNOVA Table5 indicates that Type of wire, Pulse width and Wire tension are the significant factors, which control the surface characteristics of work piece. The Model F-value of 53.34 implies the model is significant. The "Pred R-Squared" of 0.9059 is in reasonable agreement with the "Adj R-Squared" of 0.9731. "Adeq Precision" (22.52) which measures the signal to noise ratio indicates an adequate signal. Statistical analysis reveals the interaction between type of wire and wire tension, Pulse width and Wire tension. From Figure 1, it is clear that surface roughness increases with increase in pulse width whereas, both shallow and deep cryogenic treated wire exhibit improved surface finish. The adequacy of model is verified from Figure 2, which indicates that the residuals have constant variance and also are independent of one another.

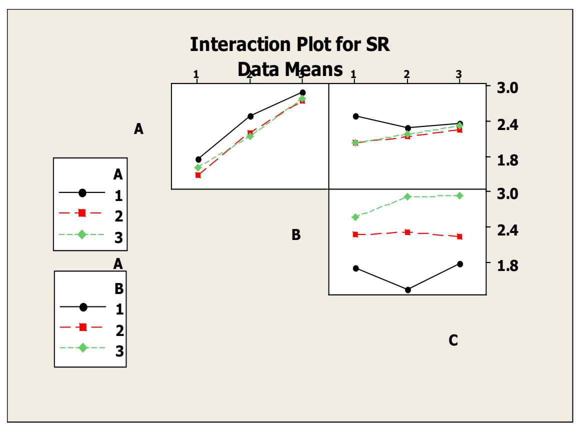


Fig. 1: Interaction Plot for SR

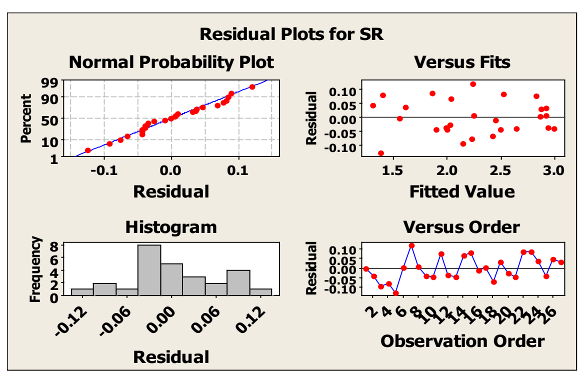
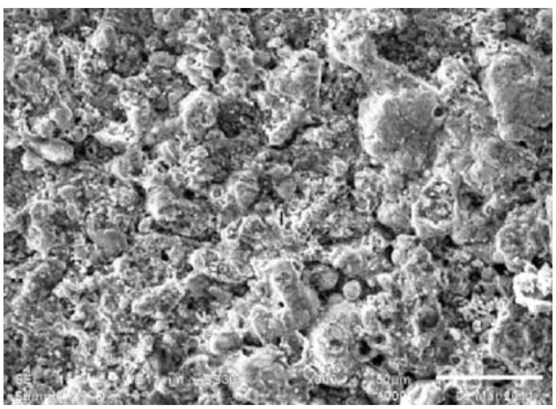


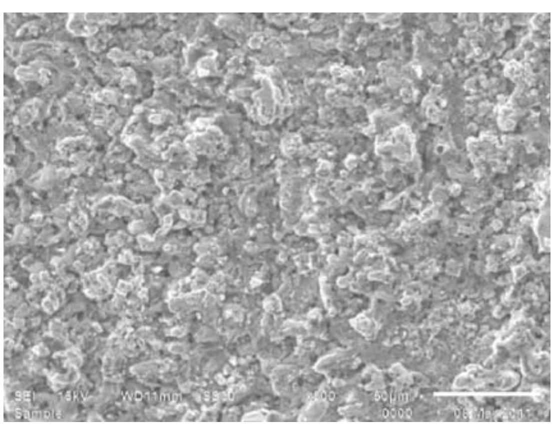
Fig. 2: Residual Plot for SR

Scanning Electron Microscopy (SEM)

The work pieces were observed with JOEL model JSM-6610LV (Detector- Everhart thornley). The scanning electron gun operated with accelerating voltage of 0.3-30KV with a pre-centered tungsten hairpin filament. The effect of untreated wire electrode on the workpiece surface roughness is evident from the Figure 3B. The workliece surface exhibits distinct and deep craters [Fig. 3B], but Surface machined by Cryogenic treated wire electrode [Fig. 3C] gives smooth appearance due to uniform, flat and shallow craters. The reasons for improvement of surface finish is that the more conductive wire in the dielectric fluid makes the discharge channel enlarged and broadened. This helps easy flushing of debris. Hence discharge energy is uniformly dispersed in all directions, which results into smaller and shallow craters on work piece. Deep craters are apparent in Figure 3D, which shows the effect untreated brass wire electrode at Pulse width 1.20 μs and Wire tension -2.0 daN.

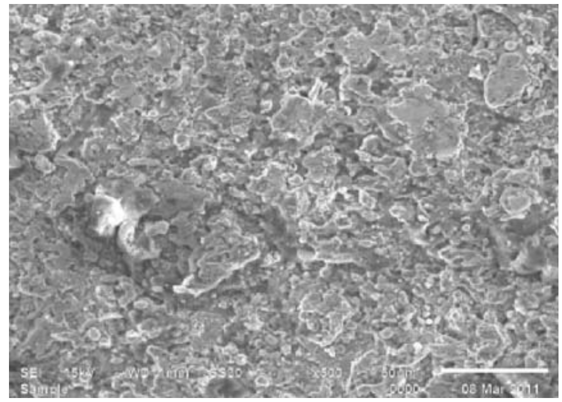


(a)

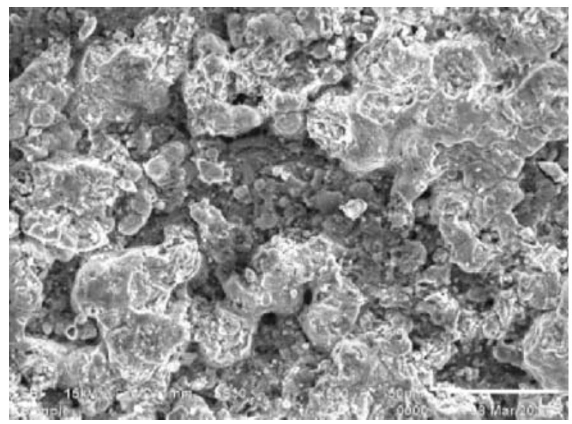


(b)

Fig. 3: Surface SEM Micrographs (X500) of Work Pieces Machined by (A) Untreated Brass Wire Electrode (B) Shallow Cryogenic Treated Brass Wire for Pulse Width- 0.4 μs and Wire Tension-0.6daN



(c)



(d)

Fig. 4: Surface SEM Micrographs (X500) of Work Pieces Machined by (C) Deep Cryogenic Treated Brass Wire for Pulse width- 0.4 μs and Wire Tension -0.6daN (D) Untreated Wire Brass wire for Pulse Width 1.20 μs and Wire Tension -2.0 daN

At high pulse width (1.2 μs) discharges are able to penetrate more into surface machined by WEDM. Surface machined with deep cryogenic treated wire (Fig. 3.4C) is the smoothest of all surfaces which confirms the SR measurements as given in Table 4.

Conclusion

Within the range of parameters selected for study following conclusions can be made;

1. Type of wire, pulse width and wire tension significantly affect the SR in WEDM.
2. Scanning electron microscope (SEM) photographs showed that cryogenic treated wires gives smoother surface than untreated wire electrode.
3. Strong interaction is observed between Type of Wire and Wire Tension; Pulse Width and Wire Tension

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